Luminescence and photocurrent spectroscopy of self-assembled InAs Quantum Wires on InP(001).

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Abstract

In this work we present the characterization by photoluminescence (PL) and photocurrent (PC) of laser structures growth by Molecular Beam Epitaxy (MBE) on InP(100) substrates with active region formed by stacked layers of InAs quantum wires (QWR).

There is increasing interest in employing semiconductor self-assembled nanostructures in optoelectronics devices, as lasers, photodetectors and amplifiers, since its exhibit unique electrical and optical properties compared with the conventional quantum well structures. In the case of quantum dot lasers, during the last couple years, a large improvement in the devices was achieved thanks to specific quantum-dot properties like extremely low threshold current densities, reduced temperature sensitivity, ultra wide gain bandwidth and reduced chirp. The most common and best developed structures employ were done with InAs quantum dots on GaAs based material systems emitting in the 1 μm to 1.3 μm wavelength range. To obtain long-wavelength (≥ 1.33 μm) in this system is very difficult even though is desirable for long-distance optical communication systems. The large lattice mismatch (7%) between InAs and GaAs makes the growth of large quantum dots difficult. Substrates of InP are preferred for these wavelength, because the lattice mismatch between InAs and InP is smaller (3%). Exactly, quantum dots on InP substrate have been shown to emit in the wavelength range of 1.2-2.0 μm with high efficiency, but only recently InP-based quantum-dash laser results were presented showing an emission wavelength of about 1.6 μm. In contrast to quantum dot formation on (100) GaAs surfaces, the InAs forms dash-like structures elongated along the [0-11] direction on InP(100) substrates. Nevertheless using (311)B InP substrate high density of spherical dots are formed and laser emission at 1.52 μm has been obtained (ref, 1-3).

In this work we present the characterization by photoluminescence (PL) and photocurrent (PC) of laser structures growth by Molecular Beam Epitaxy (MBE) on InP(100) substrates with active region formed by stacked layer of quantum wires (QWR).

The QWR are formed after deposition of ~2 monolayers (ML) of InAs (4). The waveguide is formed by a lattice matched (GaInAs)x/(InP)y short period superlattices (SPSL). The 20nm thick spacers between each layer of QWR and the waveguide are formed by a SPSL with x=4 and y=5 used.

Photoluminescence was dispersed with a 0.22m monochromator and detected with an InGaAs extended photodetector. Short wavelength excitation (6328Å) was provided with a HeNe laser. Figure 1 shows the photoluminescence emission (PL) of a 1 and 3 stacked QWR layers laser structures from 18 to 300 K. Broad emission associated with QWR are measured for wavelength

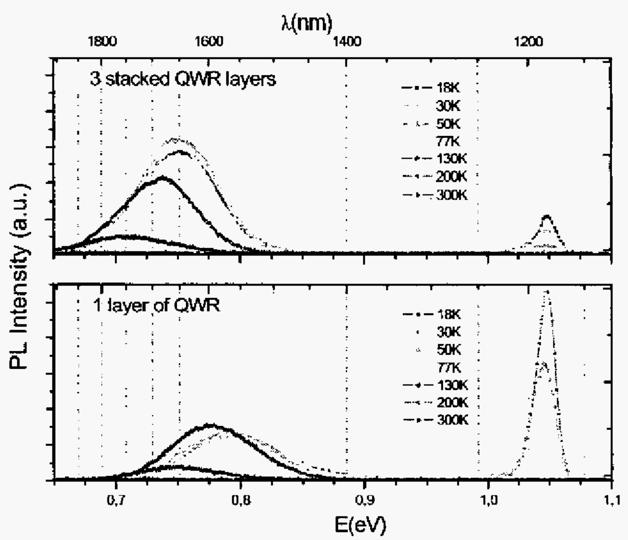

Fig1. Photoluminescence emission (PL) of a 1 and 3 stacked QWR layers laser structures. Broad emission associated with QWR is measured for wavelength longer than 1.5 microns. The PL peak centred at 1180 nm corresponds to the waveguide.

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longer than 1.5 microns. The PL peak centred at 1180 nm corresponds to the waveguide. This PL emission reduces to cero for temperatures higher than 77K due to the thermal escape of the carriers. Some of these carries can reach the QWRs increasing the intensity of the QWRs PL peak from 18 to 77K. Them the QWRs PL peak decrees rapidly with temperature and the PL signal at 300K is very low. For these reasons we think that this SPSL (4/5) gives a poor confinement of the carriers into the QWRs.

Photocurrent (PC) spectroscopy has been applied extensively in order to study the extremely weak absorption of InAs-GaAs quantum dot ensembles. In contrast to other absorption methods (photoluminescence excitation, transmission), photocurrent is a fast and comparatively simple technique which reveals unambiguously the true single-particle energy level structure of self-assembled quantum dots. With a single layer of dots embedded in the intrinsic region of a p-i-n diode structure, carriers can be resonantly excited in the dots and can then either undergo radiative recombination, or they can escape from the dots where they are collected as a measurable photocurrent.

Devices for photocurrent measurements consisted of 400µm diameter circular mesas with annular metal top contacts. The photocurrent is excited using light from a halogen lamp through a 0.22m monochromator and is detected with standard lock-in techniques.

The electric-field, F, in the intrinsic region (width = wi) of a p-i-n structure is controlled by the applied bias, VA, and the built-in junction potential, VB (~1 V for InP p-i-n diodes), according to the relation F= (VB+VA)/wi where VA is the reverse applied bias. In our laser devices the intrinsic region is form by the undoped waveguide with QWRs.

When optical excitation is provided by a photon of energy hν, resonant with a QWRs transitions, an electron-hole pair may be excited in the QWRs. If these carriers escape from the QWRs, either by tunnelling through the barriers or by thermally ionising into intrinsic continuum states, before recombining, they contribute to a measurable PC.

Figure 2 shows the Photocurrent spectra of 3 stacked QWR layers laser sample with reverse bias from 0 to 2 V at 18K and 200K. Possible features arising from the interband transitions of the QWRs have not been resolve in these devices. At 18K, the thermal escape of carriers is very low and tunnelling through the barriers is the main mechanism that contributes to the PC. With cero reverse bias the photocurrent generated is very low and when the reverse bias is applied the photocurrent increases with a higher slope in the range of wavelengths associated to the QWR and the waveguide absorptions. At 200K the photocurrent is elevated due to the thermal escape, even at cero reverse bias. These diodes present leakage currents for reverse bias higher than 2V.

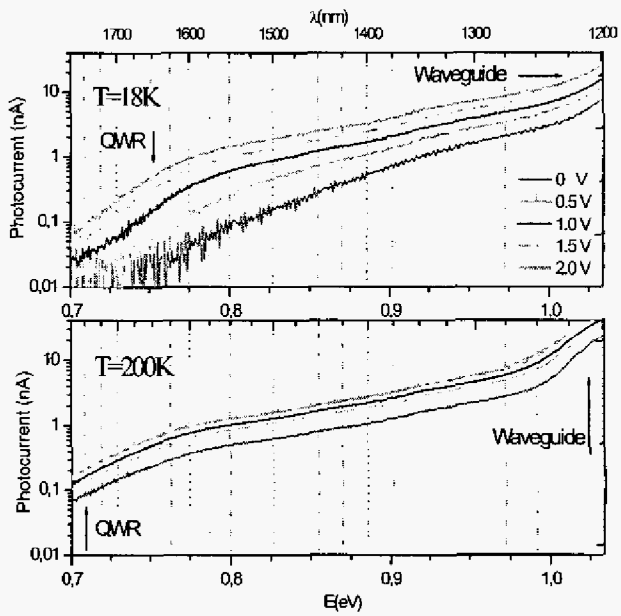

Fig 2. Photocurrent emission (PC) of 3 stacked QWR layers laser structures. The photocurrent increases with a higher slope in the range of wavelengths associated to the QWR and the waveguide absorptions.

Experimentally have been measured that there is a carrier wave function spill out from the wires confined with InP (5). In order to get better future device characteristics we have calculated the energy minibands of the superlattices (6). We have used the electron and hole activation energy from reference 7 for QWR with a photoluminescence (PL) at 1.55 microns. The confinement for the holes can be weak for some digital composition x/y=4/4 and the previously employed x/y=4/5, but other compositions show better a higher confinement. Also, we have calculated the optical confinement factor (Γ) as a function of the number of periods of (GaInAs)X/(InP)y with different x and y values. The calculations show that the 2/2 or the 2/3 SPSL

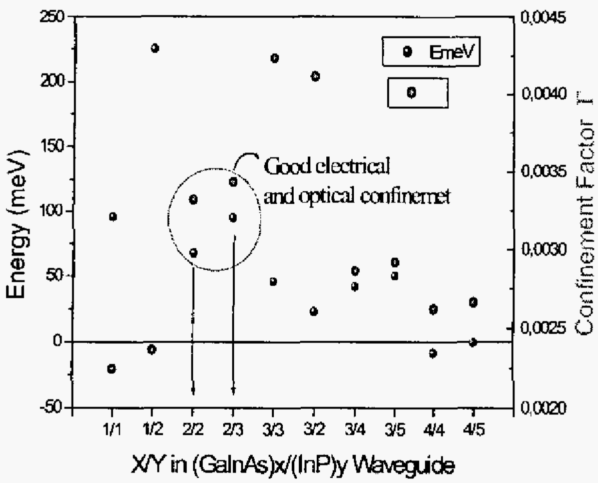

Fig3. Confinement factor (F) (red points) and activation energy of holes respect to the waveguide low energy miniband (black points), as a function of different values of x and y in (GaInAs)x/(InP)y Waveguides.

give the best optical and electrical confinement (Fig.3). Recently we have grown samples of superlattices with composition x/y=2/2 and 2/3 with and with out QWR.

In figure 4, a PL spectrum of these samples at room and low temperature is presented. Also, PL emission of InP waveguide with QWRs sample to compare. Even, at low temperatures, SPSL 2/3 with QWRs structure does not show PL emission for SPSL and show a broad band emission for longer wavelength associated with QWRs. This means that

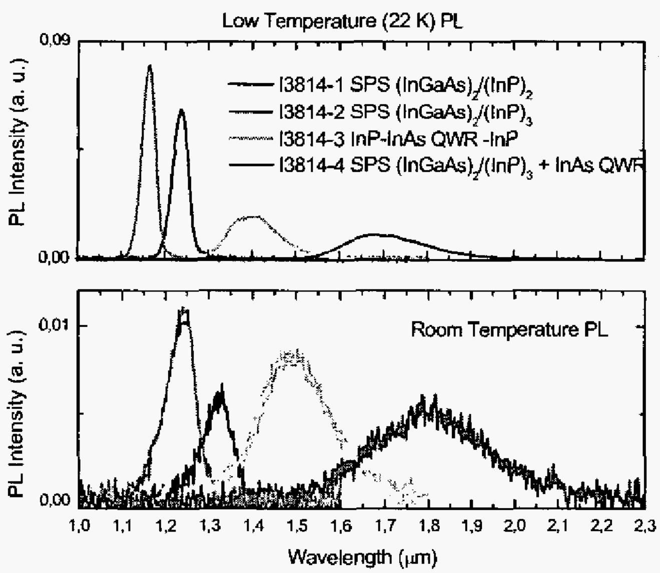

Fig 4. PL spectra of superlattices 2/2 and 2/3 at low and room temperature. Also, PL emission of SPSL waveguide with QWRs as active zone and other InP waveguide with QWRs to compare.

the SPSL 2/3 radiative time is much longer than the QWRs radiative time. The PL intensity at room temperature of this sample is the same order as the control sample. These two characteristics confirm the SPSL 2/3 as a better candidate for implement in future laser waveguides than the 4/5 traditional used.

In conclusion, we have grown laser structures with a $(GaInAs)_4/(InP)_5$ SPSL waveguide that gives a poor confinement of the carriers into the QWRs. The PL and PC characteristics show a thermal escape of carriers above 200K. We have calculated the optimun period of superlattices to minimize the escape and to increase the optical confinement.

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Acknowledgements

This work has been supported by: European Commission Sandie Network of excellence (NMP4-CT-2004-500101), European Commission NANOMAT project (G5RD-CT-2001-00545) and Spanish MCYT NANOSELF project (TIC2002-04096-C03-03).